City of Houston

Design Manual

Chapter 9

STORMWATER DESIGN REQUIREMENTS

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9.01 CHAPTER INCLUDES

A. Criteria for the design of storm drainage improvements.

9.02 DRAINAGE POLICY

A. Design Requirements.

1. Drainage criteria administered by the City of Houston and complemented by Harris County and the Harris County Flood Control District (HCFCD) for newly designed areas provides protection from Structural Flooding from a 100-year storm event. This is accomplished through application of various drainage enhancements, such as storm sewers, roadside ditches, open channels, detention and overland (sheet) run-off. The combined system is intended to prevent Structural Flooding from extreme events up to a 100-year storm.

2. Recognizing that each site has unique differences that can enhance the opportunity to provide proper drainage, the intent of these criteria is to specify minimum requirements that can be modified provided that the objective for drainage standards is maintained.

B. Street Drainage: Street ponding of short duration is anticipated and designed to contribute to the overall drainage capability of the system. Storm sewers and roadside ditch conduits are designed as a balance of capacity and economics. These conduits are designed to convey less intense, more frequent rainfalls with the intent of allowing for traffic movement during these events. When rainfall events exceed the capacity of the storm sewer system, the additional run-off is intended to be stored or conveyed overland in a manner that reduces the threat of flooding to structures.

C. Overland Run-off (Sheet Flow): Proposed New Development, Redevelopment, or In-fill Development shall not alter existing overland flow patterns and shall not increase or redirect existing Sheet Flow to adjacent private or public property. Sheet Flow from the developed property shall discharge only to the abutting public right-of-way. Where the existing Sheet Flow pattern is blocked by construction (i.e. raising the site elevation) of the Development, the Sheet Flow shall be re-routed within the developed property to return flow to original configuration or to the public right-of-way. Except under special circumstances dictated by natural drainage patterns, no Sheet Flow from the developed property will be allowed to drain onto adjacent private property.

D. Flood Control: The City of Houston is a participant in the National Flood Insurance Program (NFIP). The flood insurance program makes insurance available at low cost where the municipal entity implements measures that reduce the likelihood of Structural Flooding. The design criteria in this chapter are provided to support the NFIP. All development shall comply with Chapter 19, FLOOD-PRONE AREAS, of the Code of Ordinances if located within the City limits.

E. Relationship to the Platting Process: Approval of storm drainage is a part of the review process for planning and platting of a New Development. Review and approval of plats is conducted by the Department of Planning and Development. Review of storm drainage is conducted by the Department of Public Works and Engineering (PWE).

F. Development in Areas that have Deficient Drainage Systems: The City will consider joint project funding with a private entity for construction of drainage systems that improve existing drainage infrastructure. The City's first priority will be to fund those projects included in the Capital Improvement~~s Program~~ Plan (CIP). Where feasible, City funding will be leveraged with other funding sources including private entities, civic organizations, and other public agencies (Harris County, HCFCD, Corps of Engineers, Housing and Community Development, and other funding sources). For drainage systems that have been identified as deficient and are not scheduled to receive funding in the current CIP, the City will consider authorizing improvements performed by the private entity that comply with the City's objectives.

G. The criteria in this Chapter apply to all projects located in the City limits and to expanding utility districts and new utility districts located in the City's Extraterritorial Jurisdiction (ETJ). If the criteria conflicts with Harris County, ~~or~~ HCFCD ~~criteria~~, Fort Bend County, Montgomery County or other jurisdictions the most restrictive criteria shall govern.

9.03 REFERENCES

A. Refer to the list of references in Chapter 1, General Requirements.

B. National Weather Service Documents.

1. TP-40 Rainfall Frequency Atlas of the United States.

2. Hydro-35; 5-to-60-Minute Precipitation Duration for the Eastern and Central United States.

C. Hydraulic Engineering Circular No. 22, (HEC-22) Second Edition, "Urban Drainage Design Manual", Federal Highway Administration (FHWA).

D. ASCE Manual and Reports of Engineering Practice No. 77, Design and Construction of Urban Stormwater Management Systems, 1992.

E. HouStorm – The City of Houston's version of The Texas Department of Transportation's (TxDOT) WinStorm software.

F. HCFCD Policy, Criteria, and Procedure Manual (HCFCD Criteria Manual).

9.04 DEFINITIONS

A. Conduit - Any open or closed device for conveying flowing water.

B. Continuity Equation:

$$Q = VA$$

Where:
Q = discharge (cfs or cms)
V = velocity (ft/sec or m/sec)
A = cross sectional area of Conduit (square feet or square meters)

C. Design Storm Event - Rainfall intensity upon which the drainage facility will be sized.

D. Development – The term includes New Development, Redevelopment, and In-fill Development.

1. In-fill Development - Development of open tracts of land in areas where the storm drainage infrastructure is already in place and takes advantage of the existing infrastructure as a drainage outlet.

2. New Development – Development of open tracts of land in areas where the storm drainage infrastructure has not been constructed and a drainage outlet must be extended to a channel under the jurisdiction of the HCFCD.

3. Redevelopment - A change in land use that alters the impervious cover from one type of Development to either the same type or another type, and takes advantage of the existing infrastructure in place as a drainage outlet.

E. Drainage Area Map - Area map of watershed which is subdivided to show each area served by each subsystem.

F. FEMA - Federal Emergency Management Agency.

G. HCFCD - Harris County Flood Control District.

H. HouStorm – The City of Houston's version of TxDOT's WinStorm software. The program is available from the City or at www.swmp.org.

I. Hydraulic Grade Line - A line representing the pressure head (water surface elevation) available at any given point within the drainage system.

J. Manning's Equation:

$$V = (K/n)R^{2/3}S_f^{1/2}$$

Where:
- K = 1.49 for English units, 1.00 for metric units
- V = velocity (ft./sec or m/sec)
- R = hydraulic radius (ft. or m) (area/wetted perimeter)
- S_f = friction slope (headloss/length)
- n = 0.013 for concrete pipes, 0.015 for concrete boxes, 0.024 for CMP pipes

K. Rainfall Frequency - Probability of a rainfall event of defined characteristics occurring in any given year at a given location. Information on Rainfall Frequency is published by the National Weather Service. For the purpose of storm drainage design, the following frequencies are applicable:

1. 2-year frequency - a rainfall intensity having a 50 percent probability of occurrence in any given year, that occurs on the average every 2 years over a long period of time.

2. 3-year frequency - a rainfall intensity having a 33 percent probability of occurrence in any given year, that occurs on the average every 3 years over a long period of time.

3. 5-year frequency - a rainfall intensity having a 20 percent probability of occurrence in any given year, that occurs on the average every 5 years over a long period of time.

4. 10-year frequency - a rainfall intensity having a 10 percent probability of occurrence in any given year, that occurs on the average every 10 years over a long period of time.

5. 25-year frequency - a rainfall intensity having a 4 percent probability of occurrence in any given year, that occurs on the average every 25 years over a long period of time.

6. 100-year frequency - a rainfall intensity having a 1 percent probability of occurrence in any given year, that occurs on the average every 100 years over a long period of time.

L. Rational Formula - A method for calculating the peak run-off for a storm drain system using the following equation for run-off:

$$Q = I \times (CA)$$

Where: C = watershed coefficient
A = area (acres)
I = rainfall intensity (inches per hour)

M. Sheet Flow - Overland storm run-off that is not conveyed in a defined Conduit and is typically in excess of the capacity of the existing Conduit system.

N. Structural Flooding – The water surface elevation from the storm event exceeds the top of slab elevation of the building (for pier and beam construction the top of first floor elevation), resulting in water entering the structure.

9.05 DESIGN REQUIREMENTS

A. Design of drainage facilities shall meet requirements of the City of Houston Standard Specifications and Standard Details. HouStorm shall be used to perform design analysis and design of storm drainage systems as follows:

1. City of Houston CIP Projects – Required. In conjunction with design analysis using HouStorm, designs shall comply with guidelines provided in Technical Paper No. 100 (TP-100), Storm Sewer Design Applications for the City of Houston, Texas, Capital Improvement Plan Projects, February 2005, or the latest published date.

2. Private Projects within City Limits which include City funding participation – Required.

3. 100% Privately-funded Project located in City Limits – HouStorm preferred but alternative equivalent analysis procedures will be accepted.

4. Projects in New or Expanding Utility Districts located in City's ETJ - HouStorm preferred but alternative equivalent analysis procedures will be accepted.

B. Determination of Run-off.

1. Design Storm Events.

a. Rainfall Duration:
(1) For design purposes, the rainfall duration for drainage areas less than 200 acres will be no less than 3 hours in duration.
(2) For design purposes, the rainfall duration for drainage areas more than 200 acres will be no less than 6 hours in duration.

b. Intensity-duration Curves. Figure 9.1, City of Houston IDF Curves, depicts the intensity-duration curves to be used for storm sewer and roadside ditch design in the City of Houston and the ETJ. These curves were derived from the National Weather Service publications referenced in this Chapter.

2. Application of Run-off Calculation Models.

a. Rational Method: The rational method will be used for design on areas served by storm sewers up to 600 acres in size and for areas served by roadside ditches up to 500 acres in size.

b. Rainfall Run-off Modeling: Rainfall run-off modeling will be applied to areas greater than 500 acres in size that are drained by an open channel. Rainfall run-off modeling can be used for modeling of storm sewer areas greater than 600 acres provided the model considers the storage and ponding in streets. If the modeling is associated with establishing a flood-prone area for purposes of a FEMA submittal, the models must be acceptable to that agency.

3. Coefficients for the Rational Method.

a. Calculation of Run-off Coefficient.

(1) The run-off coefficient C values in the rational method formula will vary based on the land use. Land use types and C-values which can be used are as follows:

Land Use Type	Run-off Coefficient (C)
Residential Districts	
Lots more than 1/2 acre	0.35
Lots 1/4 - 1/2 acre	0.45
Lots less than 1/4 acre	0.55
Multi-Family areas	
Less than 20 Service Units/Acre	0.65
20 Service Units/Acre or Greater	0.80
Business Districts	0.80
Industrial Districts	
Light Areas	0.65
Heavy Areas	0.75
Railroad Yard Areas	0.30
Parks/Open Areas	0.18

(2) Alternatively, the run-off coefficient C in the rational method formula can be calculated from the equation:

$$C = 0.6ia + 0.2$$

Where: C = watershed coefficient

Ia = impervious area/total area

(3) If the alternate form is to be submitted, the calculation of C shall be provided as part of the drainage calculations.

b. Determination of Time of Concentration.
Time of concentration can be calculated from the following formula:

$$TC = 10A^{0.1761}+15$$

Where: TC = time of concentration (minutes)
A = subarea (acres)

c. Sample Calculation Forms.
(1) Figure 9.2, City of Houston Storm Sewer Calculation Form, is a sample calculation form for storm sewer systems.
(2) Figure 9.3, City of Houston Roadside Ditch Worksheet, is a sample calculation form for roadside ditch systems.

C. Design of Storm Sewers.

1. Design Frequency.

a. New Development: The Design Storm Event for sizing storm sewers in newly developed areas will be a 2-year rainfall.

b. Redevelopment or In-fill Development: The existing storm drain (sewer, ditch) will be evaluated using a 2-year design storm, assuming no development takes place. The storm drain will then be evaluated for the 2-year design event with the Development in place.
(1) If the proposed Redevelopment has a lower or equal impervious cover, no modifications to the existing storm drain are required.
(2) If the proposed Development results in the hydraulic gradient of the existing storm drain below the gutter line, no improvements to the existing storm drain are required. Detention shall comply with Paragraph 9.05.H. Flow discharged to the storm drain shall be in compliance with Paragraph 9.05.H.4.b.
(3) If the analysis of the existing conditions finds that the existing storm drain is deficient (i.e. the hydraulic grade line is above the gutter line), the applicant should check with the City to see if a CIP project is proposed that will require a capital contribution. If a CIP project is not proposed for the subject system, then on-site detention will be required in accordance with Paragraph 9.05.H. Flow discharged to the storm drain shall be in compliance with Paragraph 9.05.H.4.b.

c. City Projects (~~Capital Improvement Program~~CIP): Proposed City capital improvements may indicate a larger diameter storm sewer is planned in the area proposed for drainage improvements. The

Engineering and Construction Division of PWE has information on proposed improvements and should be consulted for impact on New Development.

d. Private Drainage Systems: Storm sewers for private drainage systems should conform to the City of Houston Uniform Building Code for development within the City limits.

2. Velocity Considerations.

a. Storm sewers should be constructed to flow in subcritical hydraulic conditions if possible.

b. Minimum velocities should not be less than 3 feet per second with the pipe flowing full, under the design conditions.

c. Maximum velocities should not exceed 8 feet per second without use of energy dissipation downstream.

d. Maximum velocities should not exceed 12 feet per second.

3. Pipe Sizes and Placement.

a. Use storm sewer and inlet leads with at least 24-inch inside diameter or equivalent cross section. Box culverts shall be at least 2 feet by 2 feet. Closed Conduits; circular, elliptical, or box, shall be selected based on hydraulic principals and economy of size and shape.

b. Larger pipes upstream should not flow into smaller pipes downstream unless construction constraints prohibit the use of a larger pipe downstream, or the improvements are outfalling into an existing system, or the upstream system is intended for use in detention.

c. Match crowns of pipe at any size change unless severe depth constraints prohibit.

d. Locate storm sewers in public street rights-of-way or in approved easements. Back lot easements are discouraged and will require a variance from the City design standards.

e. Follow the alignment of the right-of-way or easement when designing cast in place concrete storm sewers.

f. A straight line shall be used for inlet leads and storm sewers.

g. Center culverts in side lot storm sewer easements.

4. Starting Water Surface and Hydraulic Gradient.

   a. The hydraulic gradient shall be calculated assuming the top of the outfall pipe as the starting water surface.

   b. At drops in pipe invert, should the upstream pipe be higher than the Hydraulic Grade Line, then the Hydraulic Grade Line shall be recalculated assuming the starting water surface to be at the top of pipe at that point.

   c. For the Design Storm, the hydraulic gradient shall at all times be below the gutter line for all newly developed areas.

5. Manhole Locations.

   a. Use manholes at the following locations:
      (1) Size or cross section changes.
      (2) Inlet lead and Conduit intersections.
      (3) Changes in pipe grade.
      (4) Street intersections.
      (5) A maximum spacing of 700 feet measured along the Conduit run.

   b. Use manholes for existing monolithic-concrete storm sewers at the same locations as above except for intersections of inlet leads unless a manhole is needed to provide maintenance access at those intersections.

   c. Do not place manholes in driveways or in the street in front of or immediately adjacent to a driveway.

6. Inlets.

   a. Locate inlets at low points in the gutter.

   b. Valley gutters across intersections are not permitted.

   c. Inlet spacing is a function of gutter slope. The minimum gutter slope shall comply with Chapter 10, Street Paving Design Requirements. For minimum gutter slopes, the maximum spacing of inlets shall result from a gutter run of 700 feet from high point in pavement or the adjacent inlet on a continuously graded street section, with a maximum of 1400 feet of pavement draining towards any one inlet location.
      (1) Residential Development: Maximum spacing of inlets shall result from a gutter run of 700 feet from high point in pavement to the

adjacent inlet on a continuously graded street section, with a maximum of 1400 feet of pavement draining towards any one inlet location.

(2) Commercial Development: Maximum spacing of inlets shall result from a gutter run of 400 feet from high point in pavement to the adjacent inlet on a continuously graded street section with a maximum of 600 feet of pavement draining towards any one inlet location.

d. Use only City of Houston standard inlets.

Table 9.1
STANDARD STORM SEWER INLETS

INLET	APPLICATION	CAPACITY	DWG. NOS.
Type A	Parking Lots/Small Areas	2.5 cfs	02632-01
Type B-B	Residential/Commercial	5.0 cfs	02632-04
Type C	Residential/Commercial	5.0 cfs	02632-06
Type C-1	Commercial	10.0 cfs	02632-06
Type C-2	Commercial	15.0 cfs	02632-06
Type C-2A	Commercial	20.0 cfs	02632-06
Type D	Parking Lots	2.0 cfs	02632-07
Type D-1	Small Areas	2.5 cfs	02632-08
Type E	Roadside ditches	20.0 cfs	02632-09,-10
Type H-2	Residential Commercial	5.0 cfs	02633-01,-02

e. Do not use beehive grate inlets or other specialty inlets.

f. Do not use grate top inlets in unlined roadside ditch.

g. Do not place inlets in the circular portion of cul-de-sac streets unless justification based on special conditions can be provided.

h. Place inlets at the end of proposed pavement, if drainage will enter or leave pavement.

i. Do not locate inlets adjacent to esplanade openings.

j. For new residential development, locate inlets at the center of lots and coordinate drainage system with lot site layout such that inlets are not located within the driveway between the radius end points as defined by the driveway radius intersection with the curb or edge of pavement.

k. Place inlets on side streets intersecting major streets, unless justification based on special conditions can be provided.

l. For private development with internal site drainage, only one connection is permitted to any one inlet, and that connection (lead) shall be made to the back of the inlet. Connection shall not be made to the front face and to the short sides of the inlet unless approved by the City. Design the connection not to exceed the outlet pipe capacity minus either the capacity listed in Table 9.1, Standard Storm Sewer Inlets, or calculated inlet inflow.

m. For all new construction, convey public or private alleyway drainage to an inlet prior to entering the public street drainage system.

D. Consideration of Overland Flow for the Extreme Event.

1. Design Frequency: Design frequency for consideration of ~~Sheet Flow~~ overland flow shall consider extreme storm events (100-year storm) which exceed the capacity of the underground storm sewer system resulting in ponding and ~~Sheet Flow~~ overland flow from the Development to the primary outlet.

2. Design Analysis: An overland flow analysis of the proposed drainage system shall be prepared by the design engineer. The design engineer shall submit supporting calculations, exhibits, and drawings.

a. Three analysis methods as presented in Technical Paper No. 101, Simplified 100-year Event Analyses of Storm Sewers and Resultant Water Surface Elevations for Improvement Projects in the City of Houston, Harris County, Texas Region will be acceptable to the City.

(1) Method 1: Hydraulic Grade Line (HGL) Analysis
A simplified approach to analyze and control the 100-year water surface elevation (WSEL) ~~within the public right of way~~ can be achieved by designing the storm sewer system for the 2-year frequency storm event; imposing a 100-year frequency storm event on the proposed design; calculating the hydraulic grade for the 100-year frequency event for the proposed design; and adjusting the position of the HGL to ~~below the ground elevation at the right of way line as to~~ not exceed the desired water surface elevation by increasing the size of the proposed storm sewer for selective reaches.

(2) Method 2: Qt = Qo + Qc
where Qt is the total flow conveyed,
Qo is the overland flow component, and
Qc is the calculated flow in the conduit for the 2-year design event.
The overland flow component (Qo) is computed by applying Manning's Equation to calculate the flow across the critical street cross-section along the right of way. This method accounts for flow in the storm sewer and overland flow across the street crest, but does not account for street ponding or storage.

(3) Method 3: Qt = Qo + Qc + ΔS/T
where Qt, Qo, and Qc are as defined above, and
ΔS/T is the change in storage volume relative to time ~~storage volume~~ provided in the streets and adjacent area upstream of the point of interest being analyzed.
This method uses a volumetric calculation based on a 100-year frequency storm event with a duration of 3-hours for developments less than 200 acre and 6-hours duration for developments over 200 acres. The Soil Conservation Service, TR-20 method is used to set ~~the~~ a peak triangular hydrograph shape. This method accounts for flow in the storm sewer, overland flow across the street crest, and storage within the street and adjacent area.

b. Analysis using the U.S. Environmental Protection Agency's Storm Water Management Model (SWMM) will be acceptable to the City.

3. Relationship of Structures to Street: All structures shall be higher than the highest level of ponding anticipated resulting from the extreme event analysis.

~~3~~4. ~~Calculation of Depth of Flow.~~ The parameters stated below are independent measures that shall be evaluated for each project. The limiting parameter will depend on project-specific conditions, and the most restrictive condition (the lowest ponded water elevation) shall govern.

a. Streets shall be designed so that consecutive high points in the street will provide for a gravity flow of drainage to the ultimate outlet.

b. The maximum depth of ponding at high points shall be 6 inches above top of curb.

c. The maximum depth of ponding at low points shall be 18 inches above top of curb.

d. Provide a minimum 20-foot easement to accommodate sheet flow that is routed between lots or across reserve tracts in accordance with

Section 5.07.C of the City of Houston Infrastructure Design Manual. Fence lines and other improvements shall not be constructed on or across dedicated drainage easements.

e. A drawing(s) shall be provided to delineate extreme event flow direction through a proposed Development and how this flow is discharged to the primary drainage outlet. The drawing(s) shall show a profile of the roadway (or overland flow path) from the upper reach of the drainage area to the primary drainage outlet. The drawing(s) shall be exaggerated vertical scale and shall include roadway profile at the gutter, ground profile at the right-of-way, and the hydraulic gradient for the extreme event (100-year storm), or an alternative equivalent drawing accepted by the City.

f. In areas where ponding occurs and no Sheet Flow path exists, then a calculation shall be provided showing that run-off from the 100-year event can be conveyed and remain in compliance with the other requirements of this paragraph.

g. Maximum Ponding Elevation

(1) The maximum ponding elevation for the 100-year event at any point along the street shall not be higher than the natural ground elevation at the right-of-way line. Where existing topographic conditions, project location within a special flood hazard area, and/or other site conditions preclude achieving this objective, the City will waive this requirement upon submittal of documentation and analysis prepared, signed, and sealed by a professional engineer, registered in the State of Texas. Analysis shall demonstrate that structural flooding will not occur.

(2) For new subdivisions the ponding elevations shall be no higher than 12 inches below the proposed finished slab elevations, or, if the proposed finished slab elevations are less than 12 inches above the ground elevations at the right-of-way, the ponding elevations shall be no higher than the ground elevations at the right-of-way.

E. Design of Open Channels.

1. Design Frequency.

a. Open channels shall be designed according to methods described in the HCFCD Criteria Manual.

b. Design standards for channel construction shall follow the requirements specified in the HCFCD Criteria Manual.

c. Design standards for outfalls into channels shall conform to those in the HCFCD Criteria Manual.

2. Determination of Water Surface Elevation.

a. Water surface elevations shall be calculated using Manning's Equation and the Continuity Equation.

b. For the Design Storm Event, the water surface shall be calculated to remain within banks.

3. Design of Culverts.

a. Head losses in culverts shall conform to TxDOT Hydraulics Manual, Chapter 4, Culverts.

b. Corrugated metal pipe will only be approved for railroad crossings.

F. Design of Roadside Ditches.

1. Design Frequency.

a. Roadside ditch design is permissible only for single family residential lots or commercial areas equal to or larger than 0.5 acres.

b. The Design Storm Event for the roadside ditches shall be a minimum of 2-year rainfall.

c. Design capacity for a roadside ditch shall be to a minimum of 0.5 feet below the edge of pavement or 0.5 feet below the natural ground at right-of-way line, whichever is lower.

d. The design must include an extreme event analysis to indicate that structures will not be flooded, and maximum ponding elevation for the extreme event complies with Paragraph 9.05.D.3.

2. Velocity Considerations.

a. For grass-lined sections, the maximum design velocity shall be 3.0 feet per second during the design event.

b. A grass-lined or unimproved roadside ditch shall have side slopes no steeper than three horizontal to one vertical (3:1), or as soil conditions will permit.

c. Minimum grades for roadside ditches shall be 0.1-foot per 100 feet.

d. Calculation of velocity will use a Manning's roughness coefficient (n) of 0.045 for earthen sections and 0.025 for ditches with paved inverts.

e. Use erosion control methods acceptable to the City when design velocities are expected to be greater than 3 feet per second.

3. Culverts.

a. Culverts will be placed at all driveway and roadway crossings, and other locations where appropriate.

b. Culverts will be designed assuming inlet control.

c. Roadside culverts are to be sized based on drainage area. The minimum culvert size shall be 24 inches unless the option for multiple smaller size culverts is approved by the City Engineer. When requested, calculations shall be provided for review. Culvert shall be placed to be a minimum of 4 inches and no more than 8 inches below the ditch flow line. Existing roadside ditch on both sides of the proposed culvert shall be regraded for positive drainage to the nearest intersection or up to 500 linear feet whichever is smaller. In the ETJ, the Regulations for Harris, County, Texas for the Construction of Driveways and/or Culverts on County Easements and Rights-of-Way shall govern.

d. Cross open channels with roadside culverts no smaller than 24 inches inside diameter or equivalent. The size of culvert used shall not create a head loss of 0.20 feet greater than the normal water surface profile without the culvert.

e. Stormwater discharging from a ditch into a storm sewer system must be received by use of an appropriate structure (i.e., stubs with ring grates or Type E inlets).

4. Invert Protection.

a. Ditch invert protection shall be used when velocities exceed 3 feet per second.

b. Ditch invert protection will be used at the upstream and downstream ends of all culverts.

5. Depth and Size Limitations.

a. Maximum depth shall not exceed 4 feet from adjacent edge of pavement.

b. Roadside ditch bottoms shall be at least 2 feet wide, unless design analysis will support a narrower width.

c. Ditches in adjoining and parallel easements shall have top of bank not less than 2 feet from the outside easement line.

G. Design of Outfalls: Outfall design shall conform to HCFCD Standards.

H. Stormwater Detention.

1. The intention of stormwater detention is to mitigate the effect of the New Development, Redevelopment, or In-fill Development on an existing drainage system. Stormwater detention volume is based on increased impervious cover and is calculated at the minimum rates set forth in Paragraph 9.05.H.3.

2. Application of Detention.

a. The use of on-site detention is required for all Developments within the City and for new or expanding utility districts within the City's ETJ. Detention will not be required if the City has developed detention capacity for a drainage watershed, and/or infrastructure improvements, to serve the drainage watershed in compliance with the requirements of this Chapter. Under these conditions, the City will consider a funding contribution in lieu of on-site detention volume constructed by the owner.

b. If New Development, Redevelopment, or In-fill Development drains directly into a channel maintained by HCFCD, then HCFCD criteria prevails. If New Development, Redevelopment or In-fill Development drains directly to a roadside ditch, drainage ditch or storm sewer maintained by Harris County then the criteria in Regulations of Harris County, Texas for the Approval and Acceptance of Infrastructure governs~~.~~; however, for all cases of multiple regulatory jurisdiction, Paragraph 9.02.G takes precedence.

c. If the drainage system outfalls directly into a channel maintained by HCFCD, and the requirements of HCFCD include payment of an impact fee, then no further impact fee will be required by the City.

d. If Redevelopment occurs without increasing the overall impervious character of the site, then no detention will be required by the City.

e. A waiver of detention requirements may be requested if the following conditions are satisfied:

(1) Development is located in an area determined by the City to not need detention due to the geographic location in the watershed, the Development's proximity to regional facilities, or the capacity of the receiving outfall facilities. Such conclusion by the City shall be supported by submittal of a Hydraulic Report as described in Paragraph 9.05.H.2.e(2).

(2) Hydraulic Report: Submit a hydraulic analysis prepared, signed, and sealed by a professional engineer, registered in the state of Texas, to demonstrate compliance with the conditions stated in this Chapter. The hydraulic analysis shall consider (1) the current developed condition of the watershed of the stormwater conveyance system, and (2) the fully developed condition of the watershed. The probable land use for the fully developed condition will be determined by the design engineer for review and approval by the City. The hydraulic analysis shall demonstrate no negative impact to upstream or downstream conditions and shall demonstrate that a positive impact will be achieved (reduced flood crest) due to the exemption.

3. Calculation of Detention Volume.

a. Detention volume for Development areas is calculated on the basis of the amount of area of increased impervious cover.

b. Areas less than 1 acre: Detention will be required at a rate of 0.20 acre feet per acre of increased impervious cover. ~~Single family residential tracts of 15,000 square feet in area or less are exempt from detention.~~ The subdividing of larger tracts into smaller tracts of 1.0 acre and less will require the detention volume of 0.5 acre-feet per acre of increased impervious cover. Single family residential tracts of 15,000 square feet in area or less are exempt from detention. This exemption does not apply if more than one dwelling unit is located on the tract.

c. Areas between 1 acre and 50 acres: Detention will be required at a rate of 0.50 acre-feet per acre of increased impervious cover.

d. Areas greater than 50 acres: Reference HCFCD Criteria Manual.

e. Private parking areas, private streets, and private storm sewers may be used for detention provided the maximum depth of ponding does not exceed 9 inches directly over the inlet, and paved parking areas are provided with signage stating that the area is subject to flooding during rainfall events.

f. Private transport truck only parking may be used for detention provided the maximum depth of flooding does not exceed 15 inches directly above the inlet and signage is provided stating that the area is subject to flooding during rainfall events.

4. Calculation of Outlet Size.

a. Detention pond discharge pipe into an existing storm sewer line or existing City of Houston ditch:
   (1) Maximum pool elevation at or below the design hydraulic grade at the drainage system outfall - The discharge line shall be sized for the Design Storm with the discharge pipe flowing full. The pond will float on the drainage system to provide maximum benefit.
   (2) Maximum pool elevation at or above the hydraulic grade at the drainage system outfall - Provide a reducer or restrictor pipe to be constructed inside the discharge line. The discharge line shall be sized for the Design Storm with the discharge pipe flowing full.

b. Reducer or Restrictor Pipes shall be sized as follows:
   (1) Allowable Discharge Rate – Use the lowest of the discharge rates described below:
      (a) Restrictor pipes will provide a combination of low level and high level controlled release from the detention basin. The low level restrictor pipe (primary orifice) shall be sized to provide a release rate of 0.5 CFS/acre when the detention basin water depth reaches 25% of full basin depth. The low level restrictor pipe (primary orifice) shall be located at the bottom of the basin to provide complete drainage of the pond. The high level restrictor pipe (secondary orifice) shall be sized to provide a combined release rate (from the primary orifice and secondary orifice) of 2.0 CFS/acre at full basin depth. The high level restrictor (secondary orifice) shall begin releasing flow when detention basin water depth reaches 75% of full basin depth. The combined rate of 2.0 CFS/acre is the approximate discharge from an undeveloped tract for the 100-year storm.

(b) Flow discharged to the storm drain shall not exceed the proportional amount of pipe capacity allocated to the Development. The proportional amount of pipe capacity allocated to the Development shall be determined by the ratio of the area (acres) of the Development (in storm drain watershed) divided by the total drainage area (acres) of the storm drain multiplied by the capacity of the storm drain.

(2) Use the following equations to calculate the required outflow orifice:

$$Q = CA\sqrt{2g}\ \sqrt{h}$$

$$D = Q^{1/2} / (2.25\, h^{1/4})$$

Where:

Q = outflow discharge (cfs)
C = coefficient of discharge
= 0.8 for short segment of pipe
= 0.6 for opening in plates, standpipes, or concrete walls
A = orifice area (square feet)
g = gravitational factor (32.2)
h = head, water surface differential (feet)
D = orifice diameter (feet)

(3) Restrictor shall be either of the required diameter or of the equivalent cross-sectional area. The orifice diameter D shall be a minimum of 0.5 feet.

c. In addition to a pipe outlet, the detention basin shall be provided with a gravity spillway that will protect structures from flooding should the detention basin be overtopped.

5. Ownership and Easements.

a. Private Facilities:

(1) Pump discharges into a roadside ditch requires the submittal of pump specifications on the design drawings.

(2) The City reserves the right to prohibit the use of pump discharges where their use may aggravate flooding in the public right-of-way.

(3) Responsibility for maintenance of the detention facility must be indicated by letter submitted to the City as part of the design review.

(4) All private properties being served have drainage access to the pond. Dedicated easements may be required.

(5) No public properties drain into the detention area.

(6) A private maintenance agreement is provided when multiple tracts are being served.

b. Public Facilities:

(1) Facilities will only be accepted for maintenance by the City within the City limits in cases where public drainage is being provided.

(2) The City requires a maintenance work area of 30-foot width surrounding the extent of the detention area. Public rights-of-way or permanent access easements may be included as a portion of this 30-foot width.

(3) A dedication of easement shall be provided by plat or by separate instrument.

(4) Proper dedication of public access to the detention pond must be shown on the plat or by separate instrument. This includes permanent access easements with overlapping public utility easements.

(5) Backslope drainage systems are required where the natural ground slopes towards the drainage basin. A basin that is within 30 feet of a parking lot or roadway with berms that drain away from the basin does not require a backslope swale. Comply with criteria provided in HCFCD Criteria Manual.

9.06 EASEMENT AND RIGHTS-OF-WAY

A. Storm sewer easement and right-of-way requirements are described in Chapter 5, Easement Requirements.

9.07 SUBMITTALS

A. Preliminary Submittals - Submittal, for review and comment, of one-line drawings is recommended and may be required as part of the platting process. One-line drawings should include:

1. Approximate definition of lots and street patterns.

2. The approximate drainage areas for each system.

3. A definition of the proposed drainage system by single line.

4. The proposed pipe diameters.

5. Any proposed drainage easements.

6. Floodplain information, including floodplain boundary, if any; FEMA map number, effective map date and zone.

B. Final Design - Submit the following for approval:

1. Copies of any documents which show approval of exceptions to the City design criteria.

2. Design calculations for time of concentration, storm line sizes and grades, and for detention facilities, if any.

3. Design calculations for the Hydraulic Grade Line of each line or ditch, and for detention facilities, if any.

4. Drainage Area Map with the following information:

   a. Existing contour map.

   b. Drainage area and sub-drainage area boundaries.

   c. Drainage area (acres) and flow quantity (cfs) draining to each inlet and each pipe segment from manhole to manhole.

   d. Extreme event (100-year) Sheet Flow direction.

   e. Existing condition and developed condition Sheet Flow direction for the surrounding properties.

5. Plan and profile sheets showing stormwater design (public facilities only).

6. Projects located within a floodplain boundary or within a floodplain management area shall:

   a. Show the floodplain boundary or floodplain area, as appropriate, on the one-line drawing or Drainage Area Map.

   b. Comply with all applicable submittal requirements of Chapter 19, Code of Ordinances.

7. Profile drawing of roadway (or overland flow path) with exaggerated vertical scale from the upper reach of drainage area to the primary drainage outlet. Show roadway profile at gutter, ground profile at the public right-of-way, and hydraulic gradient for the 100-year extreme event; or an alternative equivalent drawing accepted by the City.

8. Calculation for proportional amount of pipe capacity allocated to the Development along with the drainage area map used for these calculations.

C. Signature Stage - Submit the following for approval:

1. Review prints.

2. Original drawings.

3. Stormwater detention maintenance agreement letters.

4. Drainage Area Map with the following information:

   a. Existing contour map.

   b. Drainage area and sub-drainage area boundaries.

   c. Drainage area (acres) and flow quantity (cfs) draining to each inlet and each pipe segment from manhole to manhole.

   d. Extreme event (100-year) Sheet Flow direction.

   e. Existing condition and developed condition Sheet Flow direction for the surrounding properties.

5. ~~Same~~ Profile drawing as specified in Paragraph 9.07.B.7.

9.08 QUALITY ASSURANCE

A. Prepare calculations and design drawings under the supervision of a Professional Engineer trained and licensed under the disciplines required by the project scope. The final design drawings and all design calculations must be sealed, signed, and dated by the Professional Engineer responsible for the development of the drawings.

9.09 DESIGN ANALYSIS

A. Projects shall be tied to National Geodetic Survey (NGS) datum adjustment which matches the Federal Emergency Management Agency (FEMA) rate maps or the most current NGS datum which matches the FEMA rate maps. In the event GPS surveying is used to establish bench marks, at least two references to bench marks relating to the FEMA rate maps shall be identified. Equations may be used to translate other datum adjustments to the required adjustment.

B. Drawing sets shall include a Drainage Area Map, which will contain calculations of flow by the rational method.

C. Drainage systems for curb-and-gutter pavements shall be underground closed Conduits; individual residential lot drainage is exempt. Drainage systems for pavements without curb and gutter shall be roadside open-ditch sections.

END OF CHAPTER